Fluid simulations of exploding pusher experiments

Stefano Atzeni

Dipartimento di Scienze di Base e Applicate per l'Ingegneria (SBAI)
Università di Roma "La Sapienza" and CNISM

Kinetic Physics in ICF 2016 Workshop
Lawrence Livermore National Laboratory
Livermore, CA, USA
April 5-7, 2016

SAPIENZA
UNIVERSITÀ DI ROMA

stefano.atzeni@uniroma1.it
http://gaps.ing2.uniroma1.it/atzeni

Acknowledgement

Collaborators

- A. Marocchino, A. Schiavi (Dip. SBAI. U. Roma “La Sapienza”)
- G. Inchingolo (MS student, U. Pisa) and G.M. Rossi (MS student, “Sapienza”)

- M. Rosenberg, R. Petrasso

Thanks to

- P. Amendt, J. Frenje, M. Gatu-Johnson, O. Larroche, H. Rinderknecht

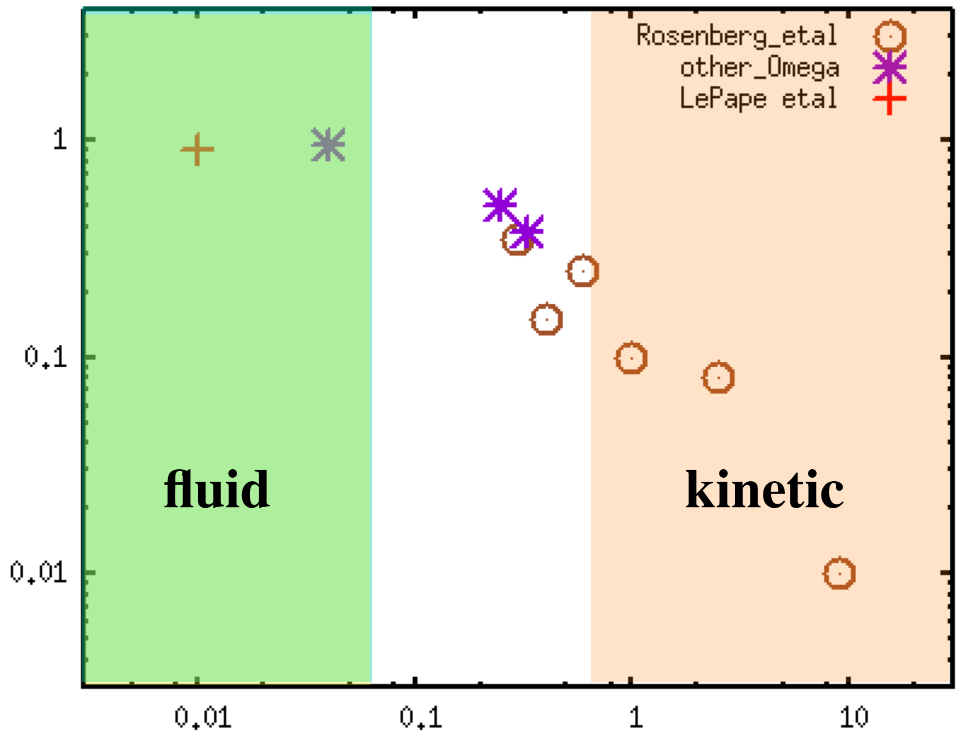
Work partially funded by MIUR-Italy PRIN project 2012AY5LEL, Sapienza project 2012C26A12CZH2

Refs:

M. J. Rosenberg *et al*., *Phys*. *Rev*. *Lett*. **112**. 014022 (2014)
M. J. Rosenberg *et al*., *Phys*. *Plasmas* **22**, 062702 (2015)
O. Larroche *et al*., *Phys*. *Plasmas* **23**, 012701 (2016)

YOC (expt vs DUED) and Knudsen number: fluid, kinetic, intermediate regimes (*)

DDn YOC vs Knudsen number



Knudsen number (@ bang time)

the rest of the presentation is restricted to fluid and intermediate regimes

Rosenberg *et al* (PRL 2014)

- D^3He filled glass shells
- R = 430 μm, ΔR = 2.3 μm
- fill density 0.4 – 3.2 mg/cm^3
- OMEGA d.d. square pulse
- E_L = 14.6 kJ in 0.6 ns

other OMEGA:

- D_2 filled glass shells
- 61085 (Rindernecht slides 2/20/13)
- 30981 (Kurebayashi *et al*, PoP 2005)
- 54853 (Shvydky, SIWorkshop 2010)

Le Pape *et al* (PRL 2014)

- D_2 or DT filled, doped CH shell
- R = 1055 μm, ΔR = 120 μm
- D (DT) density 6.33 (7.66) mg/cm^3
- NIF, rad. drive (2 steps),
- 900 kJ, 325 TW, T = 290 eV

Simulations with the fluid code DUED
"A *standard* ICF code"

Is really everything standard, validated and established in the area of ICF fluid codes? What about red items below?

- 2D, mainly used as 1D for the present study
- Lagrangian hydrodynamics, with artificial viscosity
- 2 temperatures, e-i exchange
- flux-limited e-conductivity (or non local e-transport, Schurtz et al, *PoP* 2000)
- flux-limited ion conductivity
- ion viscosity (1D only)
- our EOS
- multi-group flux-limited radiation diffusion
- LTE or nonLTE opacities (in-house modified SNOP code by Eidmann et al.)
- nuclear reactions
- charged fusion product multigroup diffusion (not used here)
- Monte Carlo neutron transport
- 2D or 3D laser raytracing (2D used here), with inverse bremsstrahlung absorption

Ion viscosity in ICF fluid codes

- Shock thickness ≈ ion mean free path λ_{ii}
- In most ICF situations $\lambda_{ii} << \Delta R$ (mesh size)

$\Rightarrow$ artificial viscosity needed to stabilize inviscid hydrodynamics;
all ICF codes include artificial viscosity;
a few also include ion viscosity (eg LASNEX, DRACO, IMPLO=old 1D-DUED)

- When λ_{ii} comparable to mesh size, ion viscosity is effective and artificial viscosity can be gradually switched off

- However, as λ_{ii} approaches velocity gradient scale-length a fluid approach is no more adequate; ion momentum transfer becomes non local.

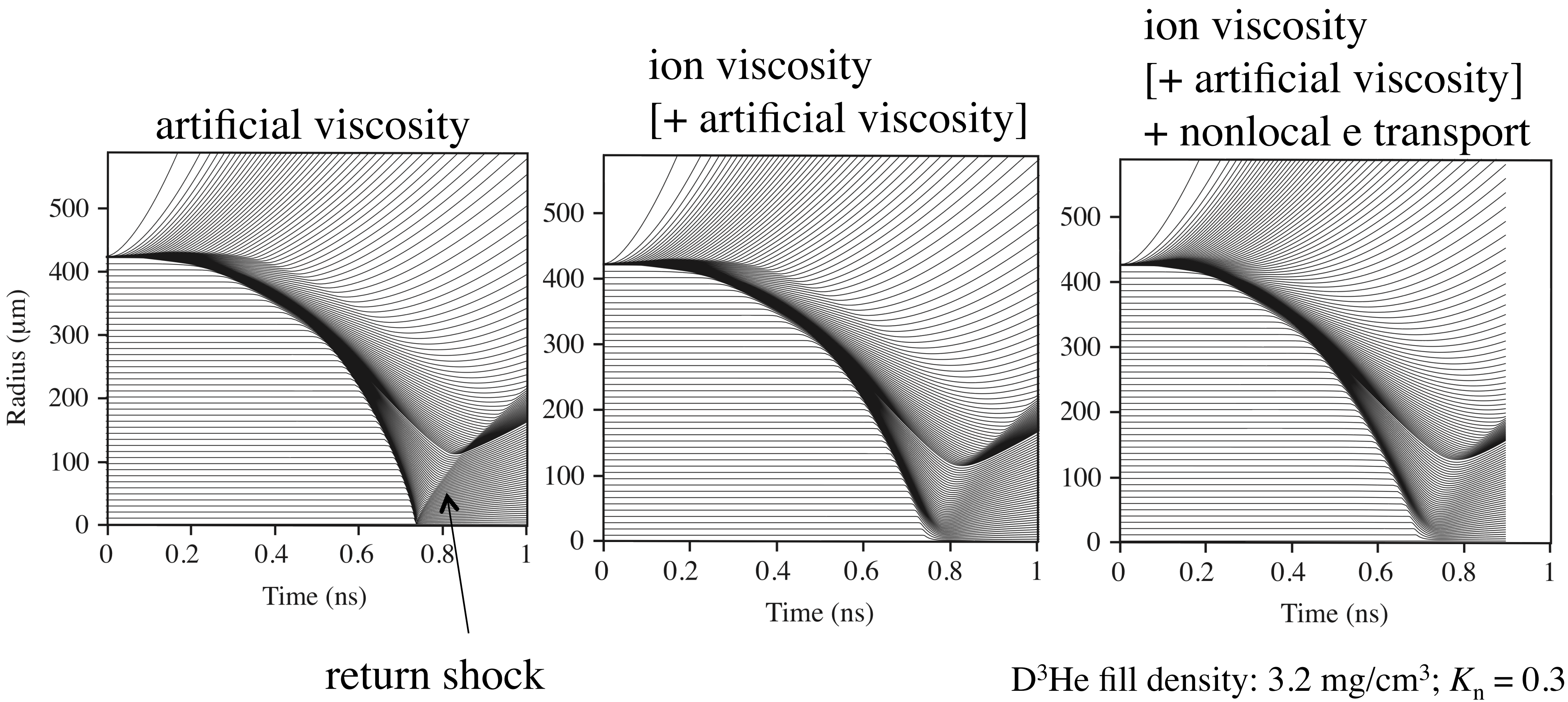
  To save causality, momentum transfer must be limited => flux-limited viscosity (just as flux-limited electron conductivity), but what about the flux limiter (*vfl*)?

$$\mu = \frac{\mu_i}{\max(1, \xi)}, \qquad \xi = \frac{|\mu_i(\partial u/\partial r)|}{(vfl)\, p_i}$$

At moderate Knudsen numbers (0.3 – 3), ion viscosity

- smooths shocks,
- reduces return shock strength,
- reduces peak ion temperature, reduces yields

- Also: T, Yield, etc. become independent of zoning

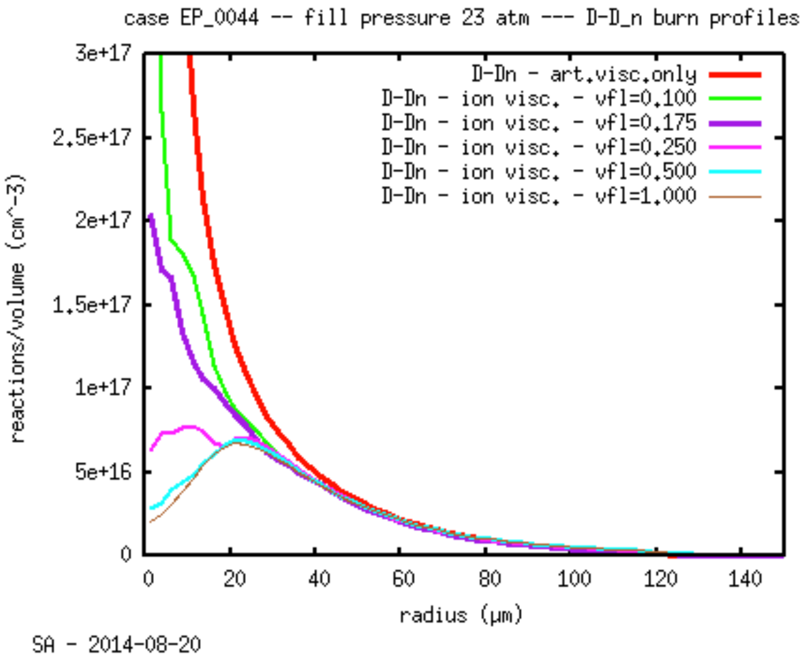


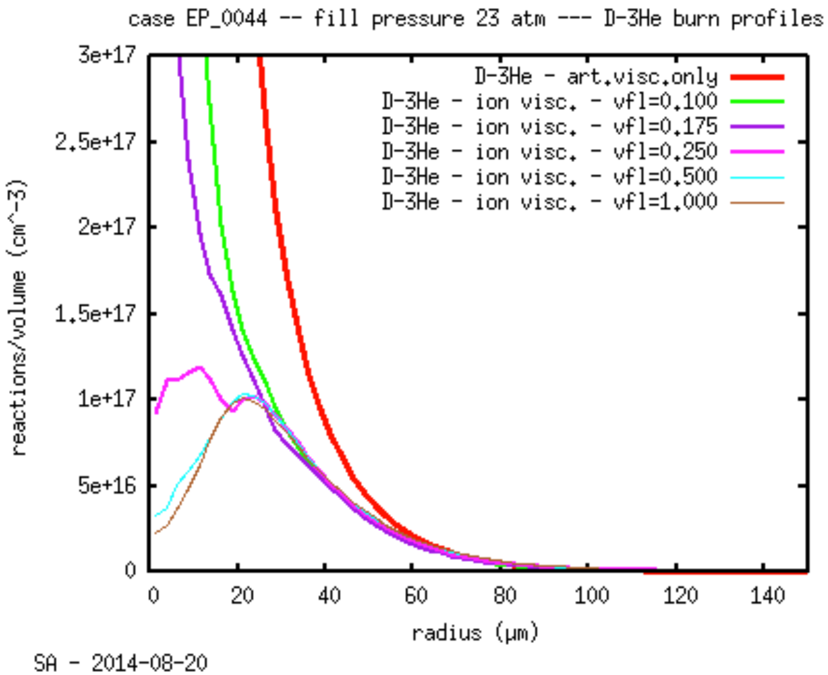
D^{3}He fill density: 3.2 mg/cm^3; $K_n = 0.3$

viscosity flux limiter drammaticaly affects burn profiles

Limiter in the range 0.2 – 0.5 produces moderately peaked profiles, as inferred by neutron penumbral imaging

Simulations always underestimate size of burning region (next vg)

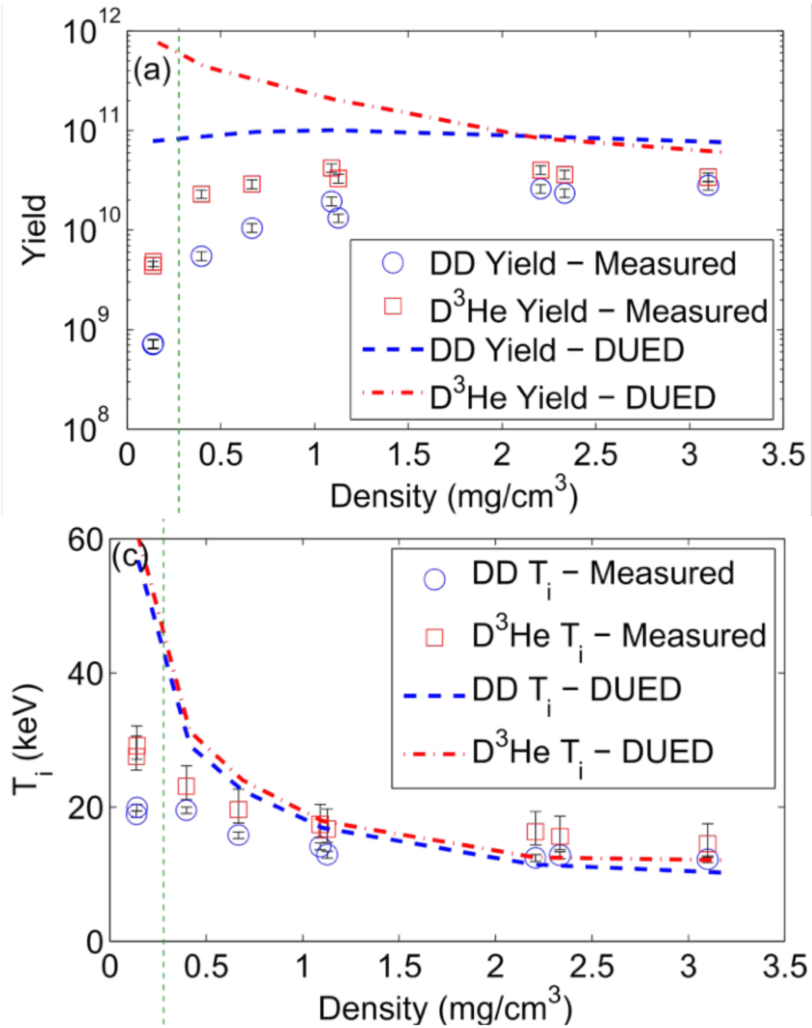


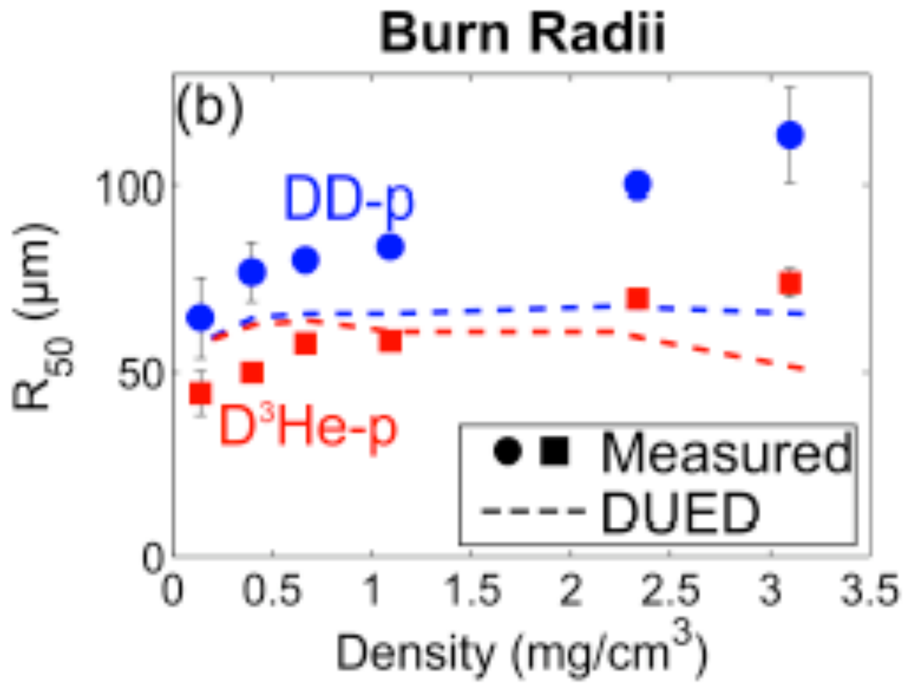


- Overall hydro unaffected by limiter
- reaction yields unaffected

As initial density increases (and ***Kn* decreases**) YOC raises, but

- **burn radii disagree**
- **simulated ion temperatures become smaller than measured ones**





M. J. Rosenberg *et al*., *PoP* **22**, 062702 (2015)

M. J. Rosenberg *et al*., PRL. **112**. 014022 (2014)

Kinetic physics or something else?

Discrepancies simulations – observations **at low–intermediate *Kn***:
- (slightly) lower ion temperature (in the sims)
- smaller burn region
- shorter burn duration
- higher ratio DDn/D^{3}He yield

really due to kinetic effects (in the shocked gas)

or, instead, to

1) modeling of drive?
2) preheating?
3) diagnostic interpretation?

1) Drive is usually "adjusted"
2) Hot electrons neglected
3) E.g., do we all measure neutron-averaged temperature in the same way?

Kinetic physics or something else?

1. modeling of drive?
2. preheating?
3. large scale 2D effects? [Assuming RTI does not affect such low aspect ratio implosions]

1. and 2.:
simulation of reference EP_0044 case (3.2 mg/cm3) **with some preheating and non-local electron transport** (and again laser power adjusted to get observed absorption), give

- YOC_DD = 0.55,
- YOC_DHe = 0.8,
- R_burn = 70–75 μm,
- R_shell = 125 μm,

all in better agreement with measured values,
but

- ion temperatures a bit lower than in previous sims,
- worst ratio of yields

Neutron-averaged temperatures

Current DUED simulations (*):

Monte Carlo generated spectra, taking into account both ion thermal motion and fluid motion (and scattering, irrelevant for the present targets)

We measure the averaged temperature from the FWHM of the spectrum (*note that since the time- and space-integrated spectrum is not Gaussian, the FWHM is no more proportional to rms deviation*).

For case EP_0044 exploding pusher we obtain T_i ≈ 10 keV, (8.5 keV neglecting fluid motion(#). From the spectrum rms we would obtain about 12 keV.

(#) An approximate estimate of fluid motion effects on temperature measurement

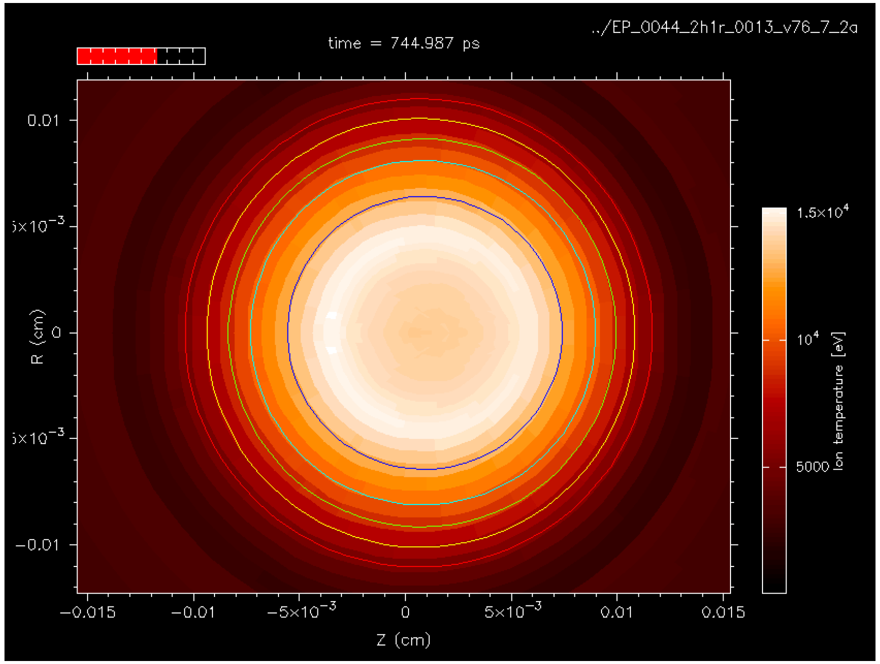
$$T_{DT} \simeq T_{DT\,\text{no motion}}(1+0.176u_7^2/T); \quad T_{DD} \simeq T_{DD\text{no motion}}(1+0.14u_7^2/T),$$

with temperatures in keV and $u_7 = \mathrm{u}/10^7$ m/s.

(*) SA and GM Rossi, *EPS 2015*, P1.203, and to be published

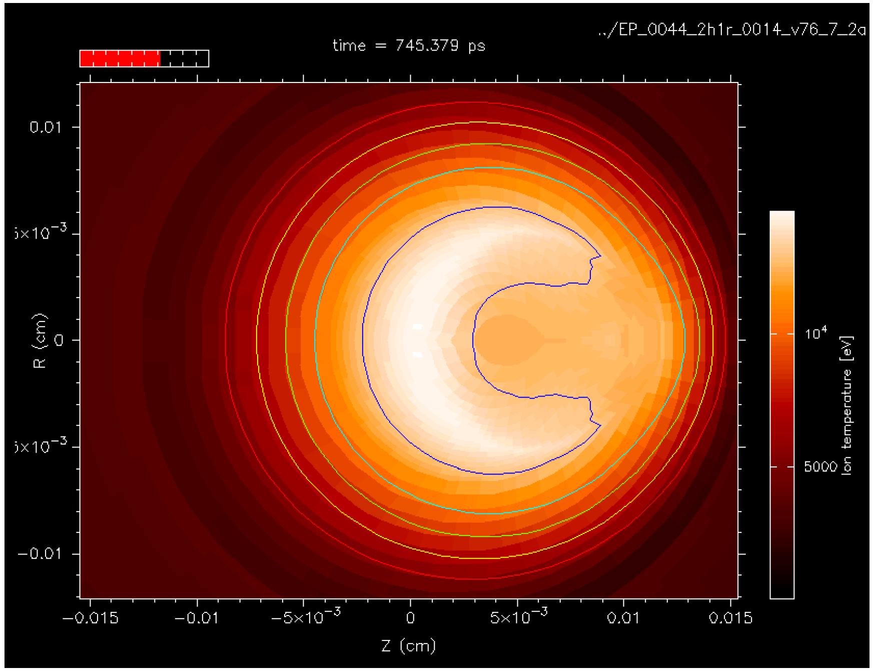
2D long scale-length effects unlikely to drastically change the overall picture

8 μm axial displacement



EP_0044_2h1r_0013

40 μm axial displacement

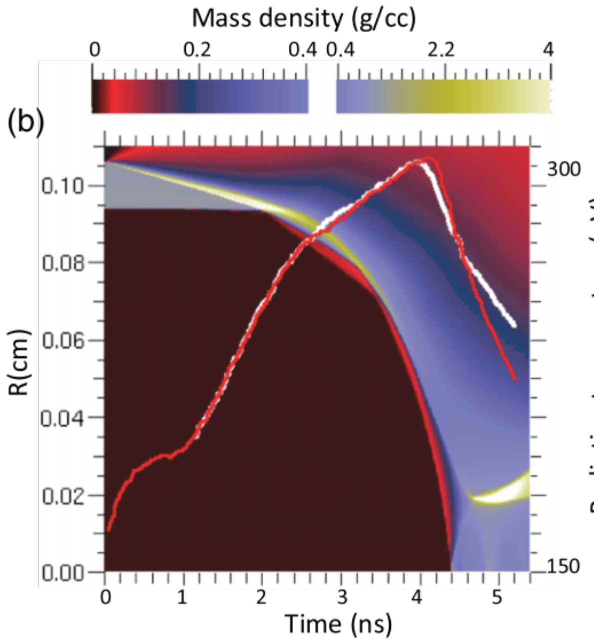


EP_0044_2h1r_0014

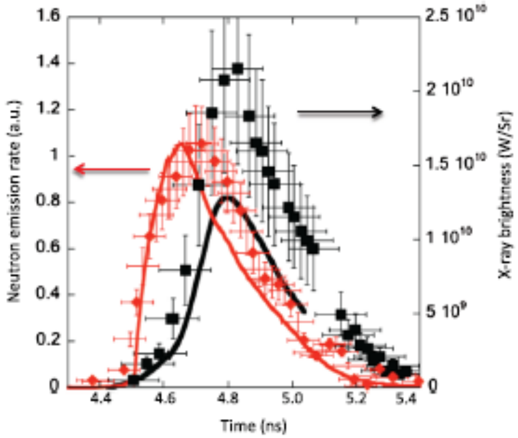
- identical yields, identical burn histories
- same as in 1D with same physical model
- same size of the hottest region (different shape)

uniform spherical irradiation, radial rays (power adjusted to give same absorption as 1D with 2D ray-tracing), flux-limited e-conduct. (0.07), artificial viscosity

Low-*Kn* limit: radiation driven exploding pusher [Le Pape *et al*.(*)] well reproduced by DUED (#) (= DUED seems *nearly* OK in the fluid purely fluid limit)



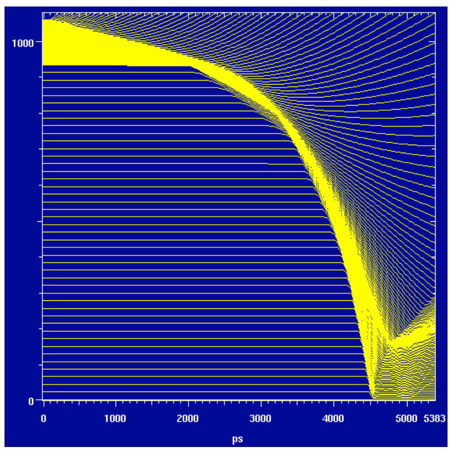
(*) PRL 112, 225002 (2014)]

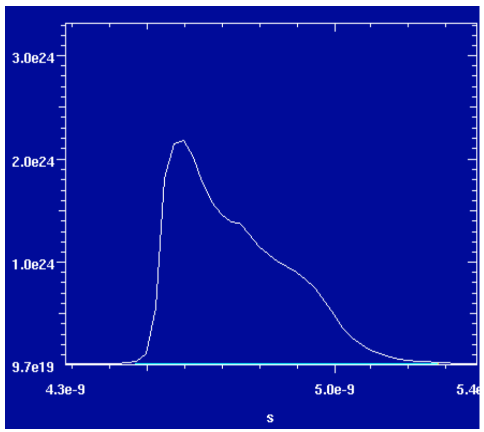


DUED simulations

YOC = 1; burn history, neutron burn radius, compressed shell radius, ρ*R* in agreement with experimental data (and HYDRA simulations). Neutron averaged temperature 10% lower.

With slighly different drive, temperature OK, but YOC = 0.6, and slightly stronger compression





(#) with drive properly adjusted: DUED cannot simulate hohlraums; we impose radiation spectrum at the outer boundary

Conclusions

Fluid simulations

- reproduce overall implosion dynamics (collapse time, implosion velocity) of exploding pushers, once the absorbed power is adjusted
- not surprisingly, cannot reproduce the lowest density imploded cores ($Kn >> 1$)
- at moderate Kn (0.3–3) reasonable agreement on integrated quantities (YOC = 0.3–0.5, temperatures within 15%), still large difference on burn radii, strong model dependence of burn profiles, wrong DD/D^3He yield ratio (worst as YOC improves) [note that codes with ion mixing have better YOC, but even smaller burn radii]

  Just kinetics, or are Kn something else? What about drive?
- At low Kn very good agreement with experiments.
  But (not discussed here for lack of time) why codes cannot reproduce the measured difference between DD and DT averaged neutron temperatures in DT implosions (Hurricane et al., *Nature* (2014)?